

Simultaneous MITSuME $g'R_cI_c$ monitoring of S5 0716+714

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ABSTRACT

We present results of our intra-night optical flux monitoring observations of S5 0716+714 done simultaneously in g' , R_c and I_c filters. The observations were done using Multicolor Imaging Telescopes for Survey and Monstrous Explosions (MITSuME) instrument on the 50 cm telescope at the Okayama Astrophysical Observatory over 30 nights between 11 March 2008 and 8 May 2008. Of these 30 nights, 22 nights have continuous (without any break) observations with duration ranging from 1 to 6 hours and hence were considered for intra-night optical variability (INOV). The remaining 8 nights have continuous observations of less than 1 hr and hence were considered only for long term optical variability (LTOV). In total we have 4888 datapoints which were simultaneous in g' , R_c and I_c filters. Of the 22 nights considered for INOV, the object showed flux variability on 19 nights with the amplitude of variability in the I_c -band ranging from $\sim 4\%$ to $\sim 55\%$. The duty cycle for INOV was thus found to be 83%. A good correlation between the light curves in all the three bands was found. No time lag between different bands was noticed on most of the nights, except for 3 nights where the variation in g' was found to lead that of the I_c band by 0.3 to 1.5 hrs. On inter-night timescales, no lag was found between g' and I_c bands. On inter-night timescales as well as intra-night timescales on most of the nights, the amplitude of variability was found to increase toward shorter wavelengths. The flux variations in the different bands were not achromatic, with the blazar tending to become bluer when brighter both on inter-night and intra-night timescales; and this might be attributed to the larger amplitude variation at shorter wavelengths. A clear periodic variation of 3.3 hrs was found on 1 April 2008 and a hint for another possible periodic variability of 4 hrs was found on 31 March 2008. During our 30 days of observations over a 2 month period the source has varied with an amplitude of variability as large as $\sim 80\%$.

Key words: galaxies:active-BL Lacertae objects: individual (S5 0716+714)

1 INTRODUCTION

Blazars form a sub-group of radio loud AGN showing extreme variability at all wavelengths, high degrees of linear polarization and strong gamma ray emission. They include BL Lac objects as well as quasars with flat radio spectra. They show variability over a wide range of timescales both within a night and over longer terms. Several models have been proposed to explain their variability; the most commonly accepted one is the shock-in-jet model (Marscher

& Gear 1985). Alternative models that probably apply under specific circumstances involve interstellar scintillation (Rickett et al. 2001), microlensing (Schneider & Weiss 1987), accretion disk instabilities (Mangalam & Wiita 1993; Chakrabarti & Wiita 1993) and binary black holes (Sillanpaa et al. 1988). However, the mechanism responsible for variability is not yet known conclusively.

Although optical variability on intra-night timescales is now a well established phenomenon for blazars (Miller et al. 1989; Carini et al. 1992; Noble et al. 1997; Stalin et al. 2005; Sagar et al. 2004), its relationship to long-term variability remains unclear. Clues to this relationship could possibly

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come from monitoring the optical spectrum for correlation with brightness (Vagnetti et al. 2003). This will also enable better discrimination among the various models proposed for flux variability in blazars.

Since the early times of BL Lac research, a correlation between spectral slope and source intensity has been searched for (Gear et al. 1986). Several authors have studied the relationship of spectral changes to flux variations over the recent years (Takalo & Sillanpaa 1989; D’Amicis et al. 2002; Vagnetti et al. 2003; Fiorucci et al. 2004; Foschini et al. 2006; Zheng et al. 2007). D’Amicis et al. (2002) reported that the spectra of all the eight BL Lacs in their sample showed a bluer when brighter trend. Similar results were obtained by Fiorucci et al. (2004) and Gu et al. (2006) also found that all the BL Lacs in their sample tend to be bluer when brighter. However some blazars are found to show anomalous spectral behaviour (Ramirez et al. 2004). For example, PKS 0736+017 showed a tendency for its spectrum to become redder when brighter both on inter-night and intra-night timescales. Gu et al. (2006) found two of their three FSQSR to be redder when they are brighter. Villata et al. (2006) reported that the FSQSR 3C 454.3 generally had the redder when brighter behaviours during the 2004–2005 outburst. No bluer when brighter trend was noticed either on intra-night or inter-night timescales for S5 0716+714 (Stalin et al. 2006), whereas BL Lac showed a bluer when brighter trend on intra-night intervals and a similar trend (although of less significance) on inter-night timescales (Stalin et al. 2006; Papadakis et al. 2007).

It is generally considered that the optical spectral index variability and the bluer when brighter trend are common for BL Lac objects (Gu et al. 2006; Papadakis et al. 2007). Nevertheless, it is currently not clear if this trend is universal in blazars as some flat spectrum quasars show the opposite behaviour. This bluer when brighter trend could be easily explained if the luminosity increase was due to the injection of fresh electrons with an energy distribution harder than that of previously partially cooled ones (Kirk et al. 1998; Mastichiadis & Kirk 2002). A second explanation for that trend posits short term fluctuations of only the electron injection spectral index (Bottcher & Reimer 2004).

As blazars are variable in timescales as short as minutes, the colour variations of blazars available in the literature all of which are based on quasi-simultaneous multi-band monitoring have relatively less utility than those obtained by simultaneous multiband monitoring. Thus there is a need to have simultaneous monitoring observations of a sample of blazars to really resolve the bluer when brighter/redder when brighter issue. Here we report new observations on the blazar S5 0716+714, which is one of the most studied sources for variability across the electromagnetic spectrum (Wagner et al. 1996; Kraus et al. 2003; Bach et al. 2005; Bach et al. 2006). This blazar also has been observed repeatedly in various multifrequency campaigns (Wagner et al. 1990; Wagner et al. 1996; Tagliaferri et al. 2003; Raiteri et al. 2003) and is known to be extremely variable (\sim hours to months at radio and X-ray bands). In the optical S5 0716+714 is identified as a BL Lac but with an unknown redshift. A redshift of $z > 0.3$ was deduced using the limits on the surface brightness of the host galaxy (Quirrenbach et al. 1991; Stickel et al. 1993; Sbarufatti et al. 2005). Nilsson et al. (2008) claim $z = 0.31 \pm 0.08$ for S5 0716+714.

The structure of the paper is as follows. Section 2 discusses the observations and reductions. The analysis of the data is detailed in Section 3 and the results are given in the final section.

2 OBSERVATIONS AND REDUCTIONS

Observations were carried out using the MITSuME 3 band ($g'R_C I_C$) simultaneous imager on the 50 cm telescope at the Okayama Astrophysical Observatory (Kotani et al. 2005). Observations were done over a total of 30 nights with duration of observations ranging from 1 to 6 hours.

MITSuME has three dichroic mirrors to divide the incident beam into three ones. It has been known that these dichroic mirrors (inclined to the incident beam by 45 degrees) produces instrumental polarization of, at most, 1.2%, 2.0% and 6.2% at g' , R_C and I_C bands, respectively. This gives a photometric uncertainty up to 1.2*p*%, 2.0*p*% and 6.2*p*%, respectively, where p is the degree of the intrinsic polarization of the object. However, the observed polarization of S5 0716+714 during the observation period was ≤ 0.15 (Mahito Sasada et al., private communication) and thus the estimated error is negligibly small, ≤ 0.003 mag even in I_C band.

The observational errors are estimated from the rms differential magnitudes between the two comparison stars

$$\sigma = \sqrt{\frac{(m_i - \bar{m})^2}{N - 1}} \quad (1)$$

where $m_i = m_c - m_k$ is the differential magnitude of the comparison star and the check star, \bar{m} is the differential magnitude averaged over the entire data set, and N is the number of observations on a given night. For each night the typical rms error ranges between 0.003 mag in I_C to 0.01 mag in g' band. The log of observations along with the average differential magnitudes between the quasar and the comparison star, comparison star and check star and their associated errors in $g'R_C I_C$ bands are given in Table 1. An asterisk against dates in Table 1 denotes the nights for which the duration of continuous observation is less than 1 hour and are not considered for intra-night optical variability analysis. Those nights are only considered for long term variability analysis.

3 ANALYSIS

3.1 Intra-night optical variability (INOV)

A total of 30 nights of observations were carried out on the source. Of these, data on 8 nights were noisy and also have continuous duration of observations less than 1 hour. These 8 nights were hence used only for long term optical variability (LTOV) analysis. Thus for INOV analysis we consider only 22 nights. To check for variability, we first constructed two differential light curves (DLCs), one between the blazar and a comparison star (C) and the other between the comparison star (C) and a check star (K). Comparison and check stars are chosen such that they are non-variable on each particular night. To say if S5 0716+714 has shown INOV in a given night, we have employed the statistical criterion of Jang & Miller (1997). This is based on a parameter C defined as C

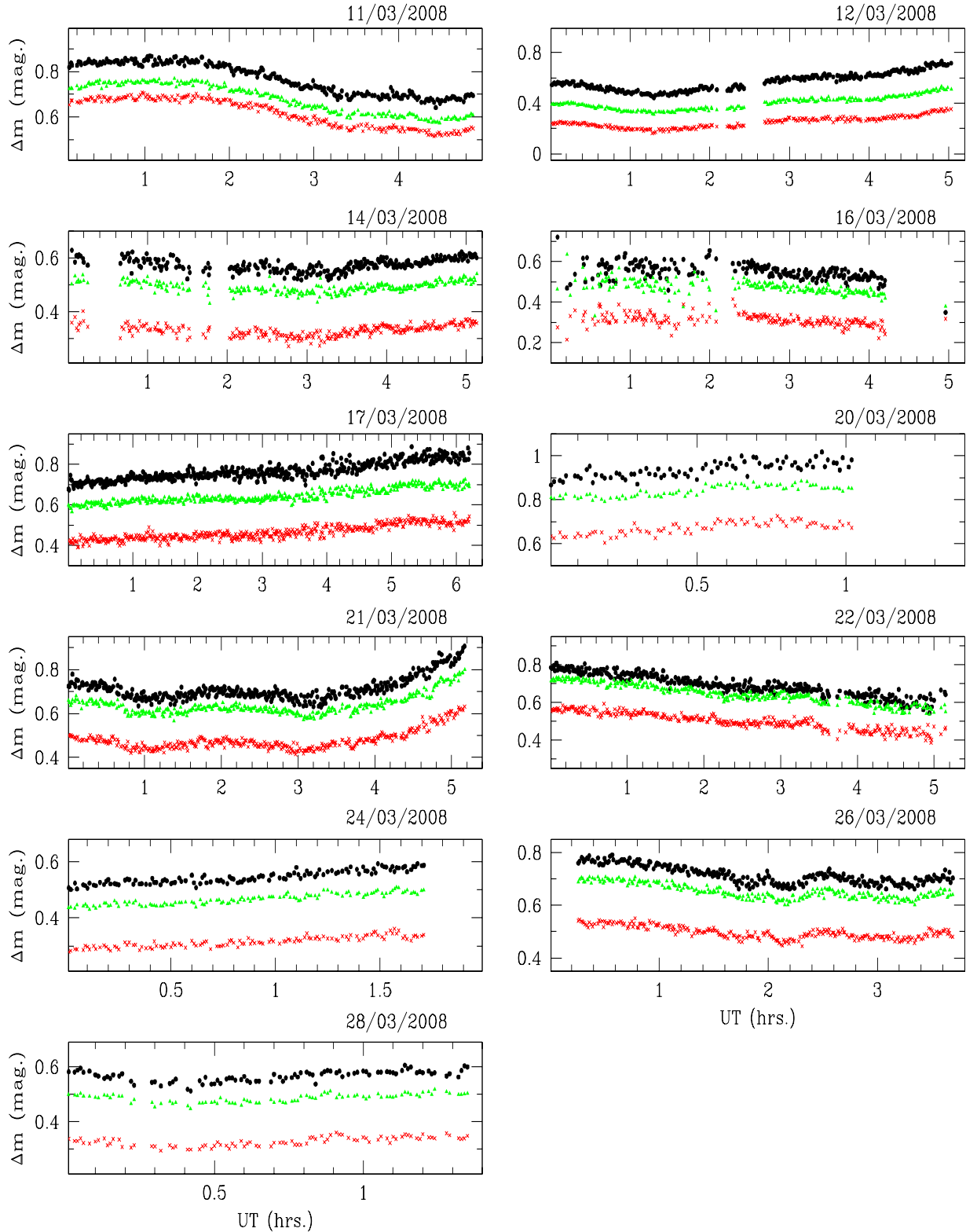


Figure 1. Differential light curves (DLCs) of S5 0716+714 in $g'R_C I_C$ filters. The DLCs in g' , R_C and I_C bands are shifted differently on each night and then shown here for clarity. The dates of observations are indicated on each panel. Here filled squares are the g' -band observations (top), filled triangles are R_C -band observations (middle) and crosses are I_C -band observations (bottom).

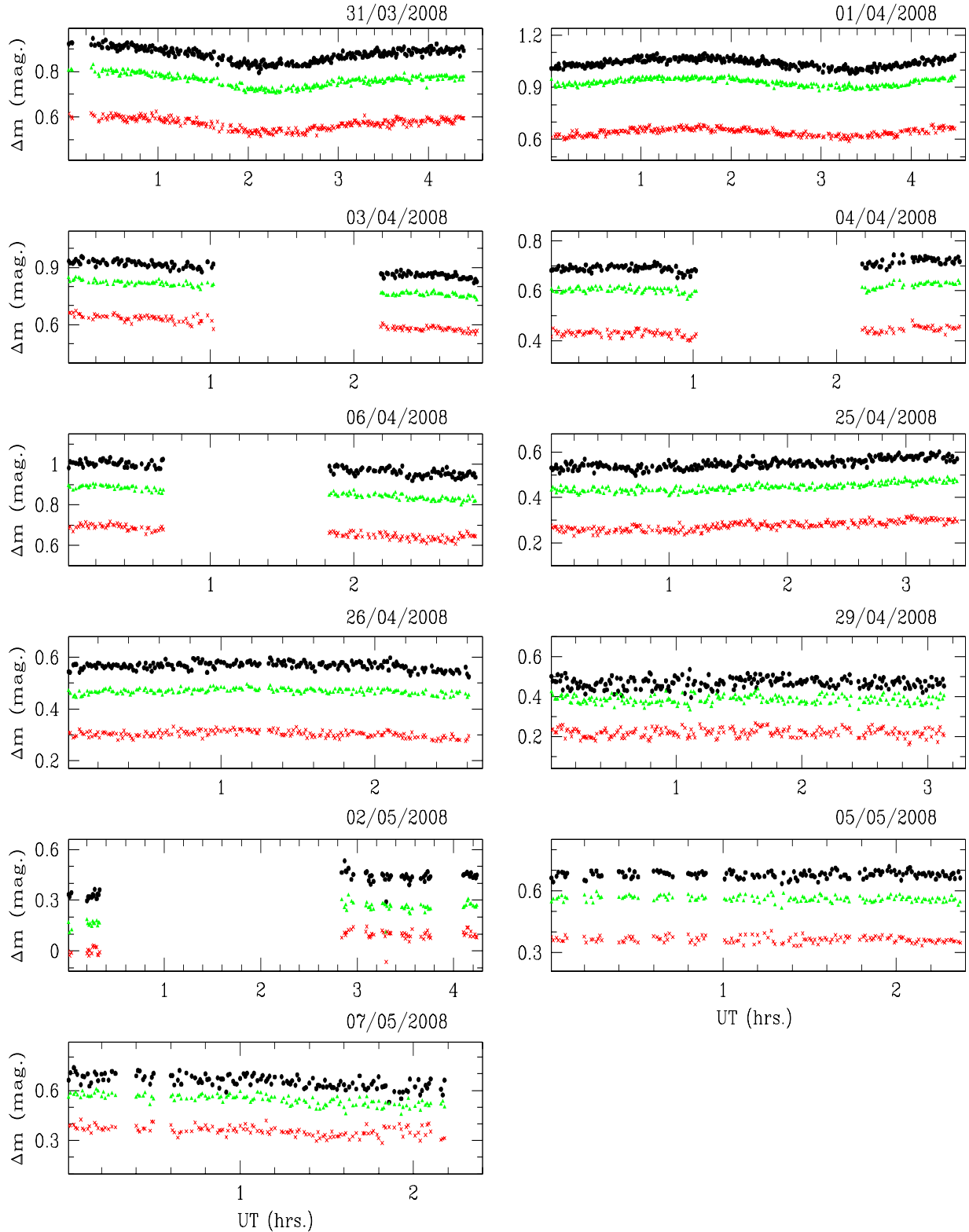


Figure 2. Differential light curves of S5 0716+714 in $g'RCIC$ filters. Details to the figure are the same as in Fig. 1.

Table 1. Log of **observations** of S5 0716+714. Here Npts is the number of data points and the number in parenthesis in this column is the number of data points in 6 minute interval. Q-C and σ_{Q-C} are the average differential magnitudes and their associated errors between the blazar and the comparison star. Similarly C-K and σ_{C-K} are the average differential magnitudes and errors respectively between the check star and the comparison star

Date	Npts	g'				R_C				I_C			
		Q-C (mag)	σ_{Q-C} (mag)	C-K (mag)	σ_{C-K} (mag)	Q-C (mag)	σ_{Q-C} (mag)	C-K (mag)	σ_{C-K} (mag)	Q-C (mag)	σ_{Q-C} (mag)	C-K (mag)	σ_{C-K} (mag)
11/03/2008	240(49)	0.769	0.069	0.280	0.010	0.779	0.065	0.125	0.004	0.617	0.062	0.038	0.003
12/03/2008	235(49)	0.470	0.070	0.278	0.009	0.501	0.052	0.123	0.005	0.350	0.044	0.035	0.004
14/03/2008	269(47)	0.475	0.020	0.304	0.011	0.492	0.017	0.137	0.008	0.332	0.018	0.044	0.005
16/03/2008	211(41)	0.452	0.045	0.279	0.037	0.474	0.033	0.131	0.025	0.316	0.027	0.041	0.007
17/03/2008	448(63)	0.669	0.042	0.281	0.012	0.645	0.033	0.122	0.005	0.467	0.034	0.035	0.004
20/03/2008	78(11)	0.839	0.030	0.303	0.006	0.841	0.024	0.125	0.003	0.673	0.024	0.038	0.004
21/03/2008	356(52)	0.615	0.053	0.304	0.013	0.637	0.045	0.133	0.004	0.480	0.044	0.045	0.004
22/03/2008	326(52)	0.589	0.054	0.284	0.018	0.639	0.051	0.123	0.007	0.497	0.043	0.032	0.003
24/03/2008	122(18)	0.447	0.023	0.294	0.008	0.468	0.020	0.125	0.004	0.315	0.017	0.037	0.003
25/03/2008*	31(6)	0.584	0.019	0.301	0.009	0.586	0.013	0.132	0.003	0.420	0.006	0.041	0.002
26/03/2008	246(36)	0.620	0.038	0.296	0.018	0.650	0.029	0.127	0.005	0.512	0.088	0.039	0.003
28/03/2008	90(14)	0.465	0.018	0.296	0.007	0.486	0.015	0.126	0.003	0.328	0.015	0.040	0.002
31/03/2008	280(43)	0.776	0.029	0.295	0.007	0.762	0.027	0.131	0.006	0.572	0.024	0.044	0.003
01/04/2008	292(45)	0.940	0.023	0.288	0.007	0.928	0.019	0.125	0.004	0.741	0.018	0.038	0.003
02/04/2008*	32(8)	0.738	0.177	0.268	0.119	0.834	0.143	0.151	0.060	0.574	0.025	0.041	0.020
03/04/2008	118(19)	0.792	0.033	0.289	0.016	0.792	0.031	0.127	0.004	0.610	0.030	0.036	0.004
04/04/2008	121(19)	0.601	0.017	0.287	0.008	0.610	0.013	0.127	0.005	0.436	0.012	0.035	0.003
06/04/2008	123(18)	0.877	0.024	0.285	0.010	0.855	0.025	0.126	0.005	0.662	0.025	0.035	0.004
08/04/2008*	42(7)	0.610	0.029	0.289	0.005	0.615	0.030	0.129	0.004	0.442	0.028	0.038	0.004
11/04/2008*	40(8)	0.552	0.020	0.287	0.011	0.528	0.014	0.121	0.010	0.350	0.014	0.040	0.005
12/04/2008*	32(7)	0.556	0.013	0.299	0.011	0.507	0.027	0.125	0.010	0.355	0.046	0.038	0.003
25/04/2008	242(35)	0.450	0.018	0.285	0.007	0.445	0.016	0.120	0.005	0.276	0.017	0.033	0.003
26/04/2008	187(27)	0.465	0.012	0.289	0.005	0.467	0.008	0.122	0.004	0.303	0.009	0.035	0.004
27/04/2008*	44(6)	0.169	0.011	0.304	0.017	0.174	0.008	0.123	0.008	0.016	0.011	0.049	0.008
28/04/2008*	79(12)	0.400	0.040	0.291	0.012	0.412	0.010	0.141	0.026	0.227	0.053	0.046	0.003
29/04/2008	204(32)	0.369	0.012	0.294	0.012	0.383	0.011	0.129	0.007	0.219	0.012	0.044	0.004
02/05/2008	66(16)	0.213	0.058	0.296	0.025	0.237	0.049	0.137	0.009	0.072	0.050	0.053	0.009
05/05/2008	136(24)	0.578	0.009	0.320	0.010	0.562	0.006	0.151	0.010	0.365	0.009	0.067	0.008
07/05/2008	131(22)	0.555	0.029	0.295	0.017	0.543	0.024	0.138	0.009	0.360	0.022	0.058	0.009
08/05/2008*	67(12)	0.690	0.034	0.307	0.023	0.651	0.023	0.131	0.013	0.475	0.016	0.053	0.009

$= \frac{\sigma_{QSO-C}}{\sigma_{C-K}}$. The source is classified as variable on any given night if $C > 2.567$ and non-variable otherwise. This corresponds to $> 99\%$ confidence level in variability. **To test for the variability of the source, we have used only the I_C band data as it has the largest S/N compared to the data in g' and R_C bands. On each night, the typical rms error in I_C -band was 0.003 mag. This is much lower compared to the corresponding rms error values of 0.007 and 0.01 in R_C and g' bands respectively.** The values of C estimated from the I_C band, the nightly variability status, duration of observations and nightly variability amplitudes are given in Table 2. From Table 2 it is clear that of the 22 nights considered for INOV, the object is clearly variable on 19 nights. The DLCs of the object on all the 22 nights are given in Figures 1 and 2. **However, we also estimated the C parameter for g' and R_C bands as well. The object passed the variability criteria in all the three bands for a total of 11 nights. On 5 nights it was variable on both R_C and I_C bands and on 3 nights it was variable when only the I_C band data was considered.**

3.1.1 Variability amplitude

We define the amplitude of variability following Romero et al. (1999)

$$\psi = \sqrt{(D_{max} - D_{min})^2 - 2\sigma^2} \quad (2)$$

where D_{min} and D_{max} refer to the minimum and maximum in the differential light curve of the object relative to a comparison star present on the same CCD frame and σ^2 is the standard deviation in the differential light curve of the comparison and check stars as given in Eq. 1. As the errors are subtracted from the total measured variability, this expression for ψ gives a fairer estimate of the true amplitude of variability in the source. The values of ψ for each nights of observations in the three bands are given in Table 2.

3.1.2 Duty cycle of variability

The duty cycle for S5 0716+714 is calculated as (Romero et al. 1999)

$$DC = 100 \frac{\sum_{i=1}^n N_i(1/\Delta t_i)}{\sum_{i=1}^N (1/\Delta t_i)} \% \quad (3)$$

Table 2. Results of flux monitoring of S5 0716+714

Date	T (hrs)	C	Status	g'			R_C			I_C		
				D_{min} (mag)	D_{max} (mag)	Amp. (%)	D_{min} (mag)	D_{max} (mag)	Amp. (%)	D_{min} (mag)	D_{max} (mag)	Amp. (%)
11/03/2008	4.9	20.667	V	0.665	0.855	18.95	0.677	0.857	17.99	0.523	0.695	17.19
12/03/2008	5.1	11.000	V	0.365	0.615	24.97	0.426	0.614	18.79	0.282	0.454	17.19
14/03/2008	5.2	3.600	V	0.435	0.509	7.23	0.465	0.528	6.20	0.299	0.376	7.67
16/03/2008	5.0	3.857	V	0.249	0.534	28.02	0.380	0.536	15.19	0.263	0.415	15.17
17/03/2008	6.3	8.500	V	0.600	0.756	15.51	0.587	0.706	11.88	0.417	0.543	12.59
20/03/2008	1.1	6.000	V	0.791	0.876	8.46	0.809	0.867	5.78	0.634	0.702	6.78
21/03/2008	5.2	11.000	V	0.556	0.783	22.63	0.585	0.786	20.09	0.431	0.621	18.99
22/03/2008	5.2	14.333	V	0.493	0.685	19.03	0.556	0.725	16.87	0.428	0.571	14.29
24/03/2008	1.8	5.667	V	0.410	0.488	7.72	0.440	0.500	5.97	0.289	0.345	5.58
26/03/2008	3.7	29.333	V	0.572	0.735	16.10	0.580	0.699	11.88	0.458	1.011	55.30
28/03/2008	1.4	7.500	V	0.436	0.488	5.10	0.465	0.508	4.28	0.305	0.348	4.29
31/03/2008	4.4	8.000	V	0.726	0.832	10.55	0.714	0.822	10.77	0.531	0.613	8.19
01/04/2008	4.5	6.000	V	0.892	0.974	8.14	0.894	0.953	5.87	0.710	0.773	6.29
03/04/2008	2.9	7.500	V	0.736	0.839	10.05	0.745	0.838	9.28	0.564	0.658	9.38
04/04/2008	2.9	4.000	V	0.569	0.629	5.89	0.582	0.630	4.75	0.413	0.462	4.88
06/04/2008	2.9	6.250	V	0.838	0.914	7.47	0.820	0.894	7.37	0.630	0.701	7.08
25/04/2008	3.5	5.667	V	0.420	0.490	6.93	0.424	0.477	5.25	0.253	0.310	5.68
26/04/2008	2.7	2.250	NV	0.430	0.483	5.25	0.449	0.482	3.25	0.286	0.320	3.35
29/04/2008	3.2	3.000	V	0.344	0.389	4.17	0.363	0.406	4.18	0.196	0.245	4.87
02/05/2008	4.3	5.556	V	0.096	0.285	18.57	0.136	0.301	16.45	-0.019	0.131	14.95
05/05/2008	2.4	1.125	NV	0.555	0.596	3.85	0.552	0.574	1.69	0.350	0.384	3.21
07/05/2008	2.2	2.444	NV	0.499	0.595	9.29	0.502	0.577	7.39	0.321	0.403	8.10

where $\Delta t_i = \Delta t_{i,obs}(1+z)^{-1}$ is the duration of the observation of the source corrected for the cosmological redshift of the i_{th} night. N_i equals 0 if the object was non-variable and 1 if it was variable during Δt_i . On the 22 nights having duration of observations between 1 and 6 hrs considered for INOV, the object was variable on 19 nights. This leads to an estimation of the duty cycle of variability of $\sim 83\%$. This is similar to the duty cycle of INOV shown by blazars (Stalin et al. 2004).

3.1.3 Cross correlations

We have used the Discrete Correlation function (DCF) method of Edelson & Krolik (1988) to check for any time lag between g' and I_C bands. Here we first calculated a set of unbinned DCFs defined as

$$UDCF_{ij} = \frac{(a_i - \bar{a})(b_j - \bar{b})}{\sigma_a * \sigma_b} \quad (4)$$

where a_i and b_j are the observed differential magnitudes in the two different filters and \bar{a} , \bar{b} , σ_a and σ_b are respectively the mean and standard deviation of the DLCs in the respective filters. DCF(τ) is obtained by binning the results in τ . Averaging over M pairs for which $\tau - \delta\tau/2 \leq \delta t_{ij} < \tau + \delta\tau/2$ gives

$$DCF(\tau) = \sum_{i=1}^M UDCF_{ij} / M \quad (5)$$

The errors in the DCF are estimated using

$$\sigma_{DCF}(\tau) = \frac{1}{(M-1)} \sum_{i=1}^N [UDCF_{ij} - DCF(\tau)]^2 \quad (6)$$

The position of the maximum in the DCF is estimated using the centroid (τ_c) of the DCF, given by

$$\tau_c = \frac{\sum_i \tau_i DCF_i}{\sum_i DCF_i} \quad (7)$$

This centroid is estimated for points which are within 80% of the peak value of the DCF. **Some examples of the computed DCF between g' and I_C band are shown in Fig. 3 . Of the 19 nights the object showed INOV, there is a clear indication of a time lag between g' and I_C bands with durations of 0.3 to 1.6 hrs on 3 nights. However, on other nights the non-existence of a time lag might be because of correlating a poor quality g' lightcurve with a relatively better quality I_C band lightcurve.** The DCF peak and centroid values are given in Table 3.

3.1.4 Variability timescale and periodicity

The presence of periodic or quasi-periodic variations in the lightcurves of blazars may provide evidence for accretion disk based models like accretion disk pulsation (Chakrabarti & Wiita 1993) and orbiting hot spot on the accretion disk (Mangalam & Wiita 1993). **In jet based models too, periodic variations can arise from jet precession and jet rotation (Reiger 2004; Camenzind & Krockenberger 1992; Gopal-Krishna & Wiita 1992).** Some reports on the presence of periodic or quasi-periodic variations in blazars are available in literature. Gupta et al. (2009) found good evidence for optical periodic variations in S5 0716+714 ranging from ~ 25 to ~ 73 minutes. Few other blazars also have shown evidence for periodic variations in their optical lightcurves. In OJ 287, on intra-night timescales, 23 min and 32 min periodicity were reported

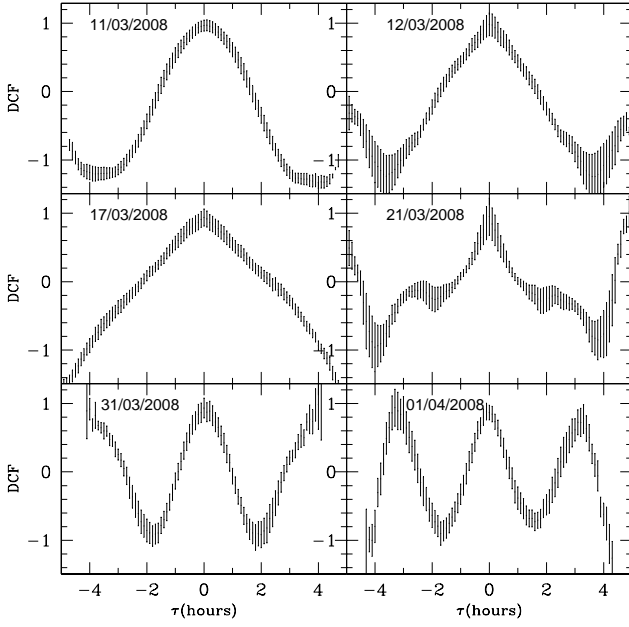


Figure 3. Some examples of Discrete Correlation Function (DCF) between the g' and I_C filters for S5 0716+714 on the nights when intra-night optical variability was observed. The dates of observations are indicated on each panel.

by Carrasco et al. (1985) and Carini et al. (1992) respectively. On inter-night timescales, a quasi-periodicity of 0.7 days seemed to be present in PKS 2155–304 (Urry et al. 1993). Hints for hour like timescale periodic variations were reported for the blazars 0851+202, 0846+513 and 1216+010 by Stalin et al. (2004). To look for possible periodicities in the new observations on S5 0716+714, we have used the first order structure function. The first order structure function is also used to find the variability time scale of the source. This is defined as (see Simonetti et al. 1985)

$$D_X^1(\tau) = \frac{1}{N(\tau)} \sum_{i=1}^N [X(i+\tau) + X(i)]^2 \quad (8)$$

where τ is the time lag, $N(\tau) = \sum w(i)w(i+\tau)$, the weighting function $w(i)$ is equal to 1 if a measurement exists for the i_{th} interval and 0 otherwise. Each point in the SF is associated with an error defined as

$$\sigma(\tau)^2 = \frac{8\sigma_{\delta X}^2}{N(\tau)} D_X^1(\tau) \quad (9)$$

where, $\sigma_{\delta X}^2$ is the measured noise variance. To estimate the SF, the data set was first transformed into uniform intervals sampled every 6 min. A typical time scale in the light curve (i.e., the time between a maximum and a minimum or vice versa) shows up as a local maximum in the SF. In the case of a monotonically increasing SF, the source possesses no typical time-scale smaller than the total duration of observations. A minimum in the SF indicates the presence of possible periods in the light curve. **For SF analysis also we have used the I_C band data as it has the lowest errors of the three bands.** Nightly variability timescales ranging from 0.1 to 5.3 hrs were found for the source. From

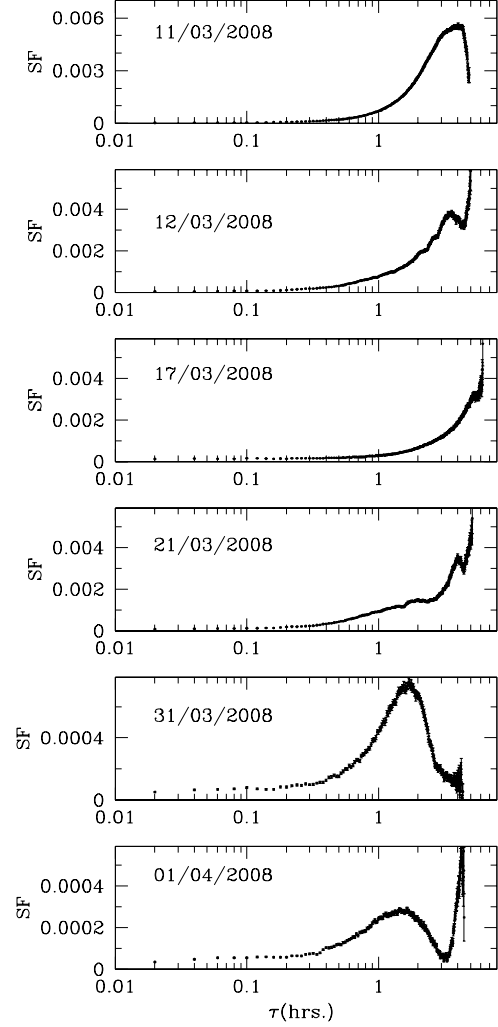


Figure 4. Some examples of structure function plots of S5 0716+714 on the nights when INOV was observed. The dates of observations are given on each panel.

SF analysis, on the 19 nights the object has shown variability, hints of quasi-periods were found on 9 nights. Of these 9 nights, clear evidence for periodic variation with 3.3 hrs was found on 1 April 2008. Also there is evidence of a possible periodic variation with a period of 4.0 hrs on 31 March 2008. This is clearly seen in the lightcurves shown in Fig.2 and is further supported by the Discrete Correlation Function analysis of the I_C band data with itself (autocorrelation). The presence of strong peaks in autocorrelation apart from the one near zero indicate a periodicity. The autocorrelation was also similar to the DCF plots shown in Fig.3. The results of the SF are given in Table 3 and **few examples of the SF plots are shown in Fig. 4.**

Table 3. Results of structure function and discrete correlation function analysis

Date	τ (hrs.)	Period (hrs.)	DCF peak (hrs.)	DCF Centroid (hrs.)
11/03/2008	4.0		0.10	0.09
12/03/2008	2.1,2.6	4.3	0.00	0.05
14/03/2007	2.0	3.9	0.00	0.00
16/03/2008	—	—	0.03	0.18
17/03/2008	5.3		0.00	-0.05
20/03/2008	0.6	0.7,0.9	0.00	-0.09
21/03/2008	1.4,1.8	1.6,2.1	0.00	0.00
22/03/2008	3.6		0.00	0.05
24/03/2008	1.3	1.4	0.00	-0.05
26/03/2008	> 3.5		0.00	0.00
28/03/2008	0.8		0.00	0.28
31/03/2008	1.7	4.0	0.00	0.00
01/04/2008	1.5	3.3	-0.10	0.00
03/04/2008	0.1	0.9	0.00	0.00
04/04/2008			0.90	0.85
06/04/2008	2.4		-0.20	-0.10
25/04/2008	2.9		0.10	-0.04
29/04/2008			1.60	1.60
02/05/2008	2.7	2.9	0.00	0.00

3.1.5 Colour Variations

From the differential instrumental magnitudes of the blazar relative to the comparison star, standard magnitudes of the blazar were obtained considering the standard magnitudes of $g' = 12.45$ mag., $R_C = 12.08$ mag. and $I_C = 11.76$ mag. for the comparison star. To check for colour evolution, the $g' - I_C$ colours were computed and plotted against the g' -band magnitudes. The colour magnitude diagrams for all the 19 nights when the object showed INOV are shown in Fig. 5. Also shown in Fig. 5 are the unweighted linear least squares fit to the data. Results of this linear regression analysis are given in Table 4. Clear evidence for a bluer when brighter trend was found on most of the nights.

3.2 Inter-night variability

The DLCs showing the inter-night variability are shown in Fig. 6. The source **was** found to vary upto 0.8 mag during the period of observations between 11 March 2008 and 8 May 2008. On inter-night time scales too, the amplitude of variability **was** found to increase toward shorter wavelengths as can be seen in Table 5. The object has shown correlated variability in all the three bands in inter-night timescales as well. The DCF between g' and I_C bands on inter-night timescales is shown in Fig. 7. We found no lag between the g' and I_C bands. In Fig. 8 is shown the colour ($g' - I_C$) magnitude (I_c) diagram of S5 0716+714 on inter-night timescales along with an unweighted linear least squares fit to the data. A bluer when brighter trend was found.

4 SUMMARY

The presence or absence of a bluer when brighter trend in blazars on inter-night and intra-night timescales can provide interesting clues to the origin of blazar activity from hour like to much longer timescale. Such a study on the spectral

Table 4. Correlation between the $g' - I_C$ and g'

Date	Slope	intercept	R
11/03/2008	0.12 ± 0.01	-0.79 ± 0.16	0.54
12/03/2008	0.39 ± 0.01	-4.22 ± 0.13	0.93
14/03/2007	0.43 ± 0.04	-4.66 ± 0.55	0.50
16/03/2008	0.84 ± 0.05	-10.01 ± 0.59	0.74
17/03/2008	0.38 ± 0.02	-4.10 ± 0.31	0.60
20/03/2008	0.49 ± 0.07	-5.66 ± 0.94	0.64
21/03/2008	0.24 ± 0.01	-2.36 ± 0.22	0.59
22/03/2008	0.32 ± 0.02	-3.39 ± 0.26	0.68
24/03/2008	0.33 ± 0.04	-3.39 ± 0.49	0.60
26/03/2008	0.39 ± 0.02	-4.24 ± 0.27	0.73
28/03/2008	0.40 ± 0.06	-4.27 ± 0.82	0.56
31/03/2008	0.30 ± 0.03	-3.01 ± 0.34	0.56
01/04/2008	0.40 ± 0.04	-4.50 ± 0.47	0.54
03/04/2008	0.17 ± 0.04	-1.42 ± 0.58	0.35
04/04/2008	0.53 ± 0.05	-6.08 ± 0.70	0.64
06/04/2008	0.21 ± 0.06	-1.93 ± 0.76	0.30
25/04/2008	0.42 ± 0.05	-4.59 ± 0.58	0.49
29/04/2008	0.92 ± 0.06	-10.93 ± 0.75	0.80
02/05/2008	0.19 ± 0.05	-1.56 ± 0.59	0.45

Table 5. Inter-night optical variability statistics

Filter	D_{min} (mag)	D_{max} (mag)	σ_{C-K} (mag)	Amplitude (%)
g'	0.145 ± 0.055	0.940 ± 0.023	0.011	79.5
R_C	0.174 ± 0.008	0.928 ± 0.019	0.008	75.4
I_C	0.016 ± 0.011	0.741 ± 0.018	0.008	72.5

variability in blazars also will help to constrain various models proposed for blazar activity. This relationship between the optical spectral variability and brightness variations in blazars have been investigated by many authors (Speziali & Natali 1998; Papadakis et al. 2003; Raiteri et al. 2003; Villata et al. 2004; Wu et al. 2005; Stalin et al. 2006). The results of such studies are contrary to each other. To address this issue, we have presented here high temporal resolution, simultaneous $g'R_C I_C$ band photometric monitoring observations of the blazar S5 0716+714 on 30 nights between 11 March 2008 and 8 May 2008. The results of our observations are summarized as follows

(i) The object was active during our whole monitoring period and showed variability both on intra-night and inter-night timescales. During individual nights, the amplitude of variability ranges from 4% to 55%. On inter-night timescale, the source has **shown** a variability as large as 80% during the whole monitoring period

(ii) Of the 22 nights considered for INOV, the object showed variability on 19 nights with an estimated duty cycle of variability of 83%. The amplitude of **variability** was found to be larger toward shorter wavelengths, both on inter-night and intra-night timescales

(iii) On the nights the object showed INOV, the timescale of variability was found to be between **0.1** hr and 5.3 hrs. Also on 9 nights evidence for quasi-periods were found with periods ranging from 0.9 to 4.3 hrs. Clear evidence for periodic variations with a period of 3.3 hrs was found on 1 April

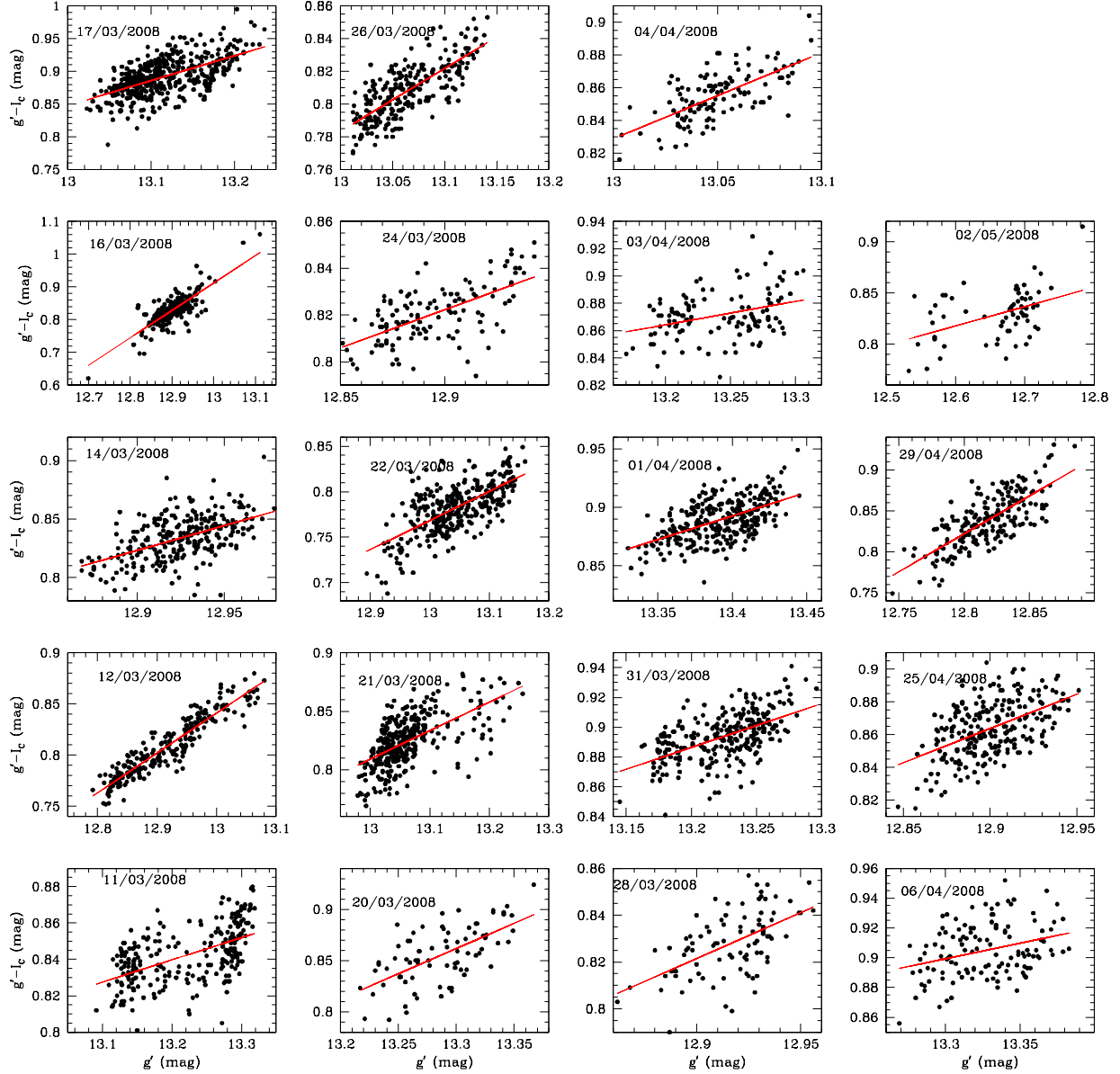


Figure 5. Colour magnitude diagram of S5 0716+714 for the nights where intra-night optical variability (INOV) was found. The dates are indicated on each panel. The solid line is the linear least squares fit to the data.

2008. A second possible periodic variation with period of 4.0 hrs was found on 31 March 2008.

(iv) No evidence for time lag was found between g' and I_C bands on most of the nights, except for three nights, when the g' band was found to lead the I_C band with durations from 0.3 to 1.6 hrs. However, on inter-night timescales, no time lag was found between g' and I_C bands.

(v) The object showed clear colour variation, in the sense the object became bluer when brighter on both intra-night and inter-night timescales.

Several models have been proposed to explain the flux variability in blazars. They are broadly grouped into two categories namely intrinsic and extrinsic. Models invoking extrinsic mechanisms as the cause of variability include interstellar scintillation (Rickett et al. 2001) and gravitational microlensing (Schneider & Weiss 1987; Gopal-Krishna & Subramanian 1991). Interstellar scintillation can be active at low radio frequencies as it is highly frequency dependent. The optical INOV seen in S5 0716+714 cannot thus be caused by interstellar scin-

tillation. Gravitational microlensing results in symmetric lightcurves and is also an achromatic process. The clear bluer when brighter chromatism seen in S5 0716+714 both on inter-night and intra-night timescales is thus not due to microlensing. These observations as well as the close correlations between the optical and radio bands seen in S5 0716+714 (Quirrenbach et al. 1991) argues strongly against an extrinsic origin of variability. The two other major classes of models for intrinsic origin of AGN variability are those involving accretion disk instabilities (Mangalam & Wiita 1993) and those involving shocks in relativistic jets (Marscher & Gear 1985). The shock-in-jet model is the most commonly used model to explain variability in blazars where relativistic jets are present. In this model time lag between various wavelength bands are expected. In our observations no evidence of a lag between g' and I_c bands was found on most of the nights. This might be due to the poor quality of the g' band data compared to the I_c band for correlation analysis. Investigations on flux variability on blazar sources, have revealed evidence of periodicity in different timescales in few cases (Gupta et al. 2009; Carrasco et al. 1985; Carini et al. 1992; Stalin et al. 2005, Wu et al. 2005). The detection of quasi-periodicity or periodicity on intra-night timescales can be most explained by accretion disk based models (Mangalam & Wiita; Chakrabarti & Wiita 1993; Espailat et al. 2008). In the context of shock-in-jet model too, periodicity in blazar lightcurves can be of geometrical origin namely orbital motion in a binary black-hole system, jet precession and jet rotation (Reiger 2004; Camenzind & Krockenberger 1992; Gopal-Krishna & Wiita 1992) and their variations are achromatic (Wu et al. 2005). In our observations on the nights when quasi-periodicities were found and on the two nights when clear sinusoidal variations were found, the variations were highly chromatic. The presence of spectral variations thus imply that the observed variations are not caused by geometric effects. Our observations on the variability in S5 0716+714, the bluer when brighter trend and the increase of the amplitude of variability towards shorter wavelengths appear to be more consistent in terms of shocks propagating in the relativistic jet of S5 0716+714. Recently Dai et al. (2009) noted that among blazars, BL Lacs show a bluer when brighter trend whereas, FSQSRs show a redder when brighter trend. This might indicate the existence of different physical conditions in these two subclasses of blazars. Further simultaneous observations of a matched sample of BL Lacs and FSQSRs are needed to fully resolve the question of the ubiquity of the bluer when brighter trend in blazars.

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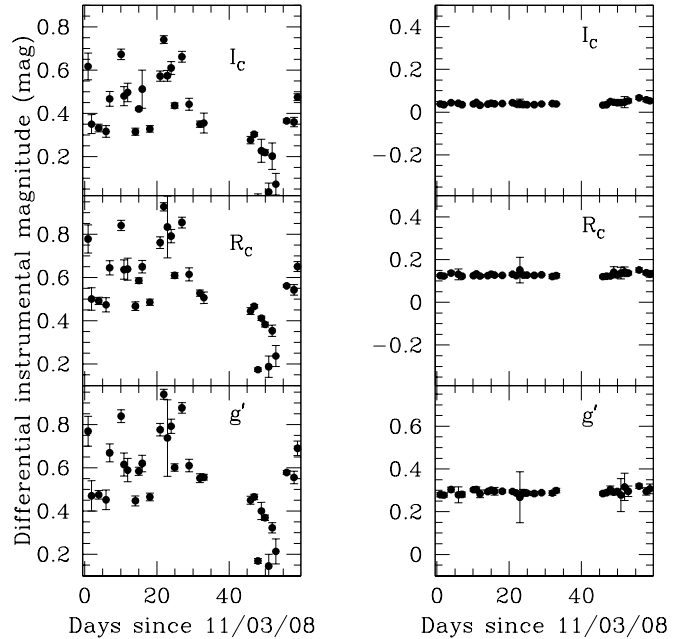


Figure 6. Inter-night optical variability of S5 0716+714 during the period 11 March 2008 to 08 April 2008. Left: Differential Light Curves in $g'RcI_c$ filters. Right: DLCs between the comparison star and the check star in $g'RcI_c$ filters.

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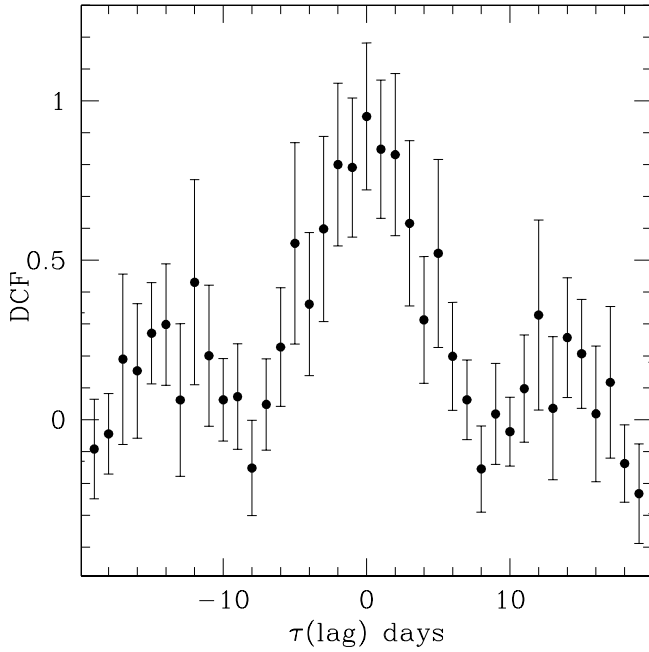


Figure 7. Discrete Correlation Function (DCF) between g' and I_c in S5 0716+714 on inter-night timescales

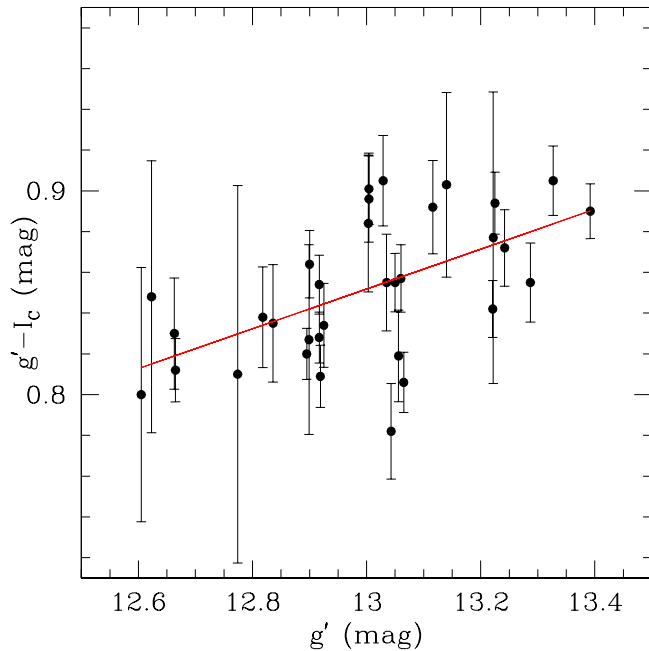


Figure 8. Colour-magnitude diagram on inter-night timescales

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